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(71) Applicant: **Foxboro Corporation**
Foxboro, Massachusetts 02035-2099 (US)

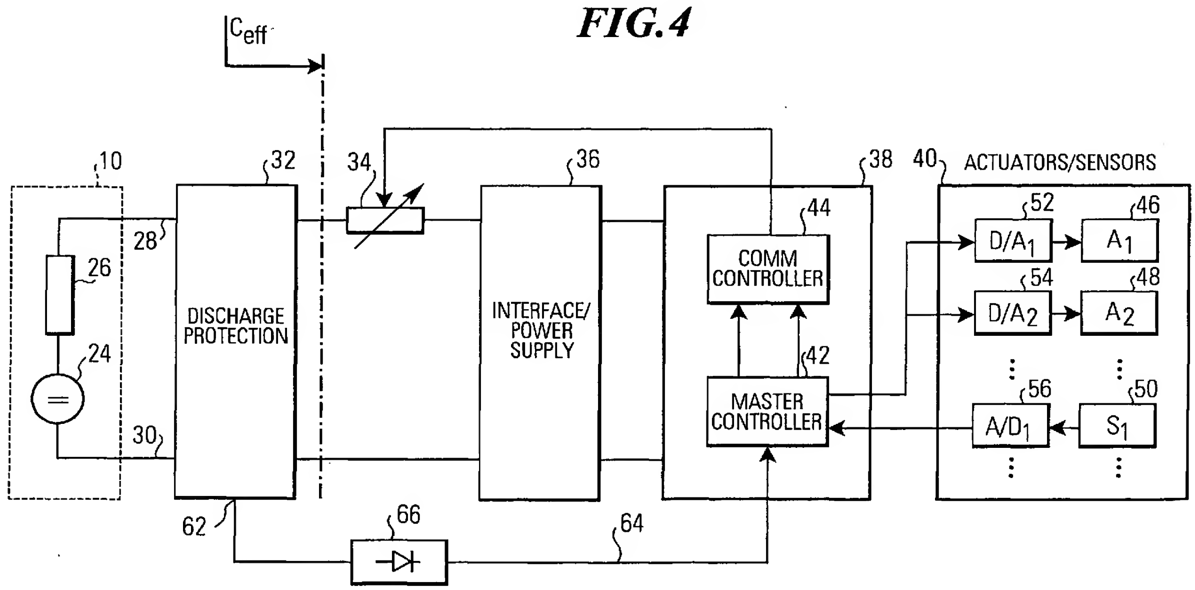
(72) Inventor: **Löchner, Michael**
70794 Filderstadt (DE)

(74) Representative: **HOFFMANN - EITLE**
Patent- und Rechtsanwälte
Arabellastrasse 4
81925 München (DE)

(54) Bus voltage detector in field device

(57) To detect a power supply failure on an intrinsically safe field bus of a manufacturing process control system in an efficient manner there is provided a field device with a discharge protection unit which is connected to a control bus (10) for supply of an operating current from the control bus (10) to the field device (20, 22). The discharge protection unit (32) inhibits a discharge of energy stored in the field device (20, 22) to the control bus (10). The field device also comprises a controller unit (38) adapted to control the operation of the field device (20, 22) and being powered with the operating current from the control bus (10). According to the present invention the discharge protection unit (32) comprises at least two rectifying elements inserted into the current path of the operating current with identical conducting directions and an input signal or an output signal of a selected rectifying element is supplied as interrupt signal to the controller unit (38) for power supply failure detection.

FIG.4



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Description

FIELD OF INVENTION

[0001] The present invention relates to a field device for monitoring a manufacturing process and for actuating manufacturing process variables, and in particular to a field device for a monitoring a manufacturing process and for actuating a manufacturing process variables having the capability for power supply failure detection.

BACKGROUND OF INVENTION

[0002] Field devices as described in the following are generally used in manufacturing processes to monitor the operation and to actuate process variables within such a manufacturing process. Typically, a plurality of actuators are placed in the manufacturing field to drive a plurality of different process control elements, e.g., valves, sensors, etc. Further, transmitters are installed in the manufacturing field to monitor process variables, e.g., fluid pressure, fluid temperature or fluid flow.

[0003] Actuators and transmitters are coupled to a control bus to receive and transmit process information to a centralized controller monitoring the overall operation of the manufacturing process. This control bus may be implemented as two wire loop carrying a current that provides a power supply for operation of the field devices.

[0004] In such control systems communication is typically executed through a field bus standard which is a digital communication standard according to which a plurality of transmitters may be coupled to only a single control bus to transmit sensed process variables to the central controller. Examples for communication standards are given in ISA 50.02-1992 section 11 and HART® relying on a digital communication on the basis of a 4-20mA processor variable signal.

[0005] An important aspect with respect to control systems of the type outlined above is intrinsic safety. When a field device is located in a hazardous area without explosion proof equipment the electronics in the field device should be intrinsically safe.

[0006] Here, intrinsic safety means that the electronics must be designed in a way that no sparks and no heat is generated thereby even when one or more electronic component failures occur at the same time.

[0007] Usually intrinsic safety is achieved through additional protecting elements protecting the electronics under a failure condition. Depending on the specific type of application - e.g., the explosive type of gas which is used within a manufacturing process - there prevail different design specifications and certifications for the protecting elements.

[0008] Fig. 1 shows a peripheral part of a manufacturing process control system.

[0009] As shown in Fig. 1, the peripheral part of the control system may comprise a first bus segment 10 of the intrinsic safe type and a second bus segment using, e.g., the RS485 standard for data communication. The intrinsically safe field bus segment 10 and the RS485 bus segment 12 are coupled through a bus coupler 14. Further, the side of the intrinsically safe field bus segment 10 being not attached to the bus coupler 14 is connected to a terminating circuit that allows to avoid reflections on the intrinsically safe field bus segment 10.

[0010] As also shown in Fig. 1, to each bus segment 10, 12 there is connected at least one field device 18, 20, and 22. Each field device is either an actuator, a transmitter or another I/O device receiving/transmitting information.

[0011] Further, the field devices attached to the intrinsically safe field bus segment 10 may be powered through an electric current received from the intrinsically safe field bus segment 10 leading to a voltage drop across the field devices 20, 22. Typically, the intrinsically safe field bus segment 10 will be operated under a field bus protocol or any other appropriate protocol allowing to exchange digital information.

[0012] As shown in Fig. 1, operatively the field devices 20, 22 coupled to the intrinsically safe field bus segment 10 exchange information through modification of the current flowing into each field device 20, 22. For digital communication a basic value of the current of the intrinsically safe field bus segment 10 is modulated to be increased or decreased by predetermined offset value, i. e. 9 mA for the field bus standard. This modulation of the current flowing into either the field device 20 or the field device 22 leads to a modification of the voltage U_B on the intrinsically safe field bus segment 10 thus achieving digital communication.

[0013] Fig. 2 shows a more detailed schematic circuit diagram of the field devices shown in Fig. 1.

[0014] As shown in Fig. 2, the intrinsically safe field bus segment 10 may be summarized into an equivalent circuit diagram with an ideal voltage source 24 and a resistor 26 to model AC voltage impedance and to fulfil intrinsic safety requirements for a spark protection, current limitation and power limitation in an hazardous area.

[0015] As also shown in Fig. 2, each field device is connected to the intrinsically safe field bus segment 10 with two wires 28, 30 being also connected to a discharge protection unit 32. At the output of the discharge protection unit 32 there is provided a modulating unit 34 which allows to modulate the operating current flowing into the field device.

[0016] The modulating unit 34 is connected in series to a power converter unit 36 that is adapted to map the operating current flowing over the modulating unit 34 into a suitable power supply signal for a control unit 38 connected to the output of the power conversion unit 36 and an actuator/sensor unit 40 being controlled by the controller unit 38.

[0017] As also shown in Fig. 2, the controller unit 38 is divided into a master controller and a communication

controller 44. While the communication controller 44 controls the operating current modulating unit 34 to achieve a modulation of the operating current and therefore exchange of information between the intrinsically safe field bus segment 10 and the field device the main control of the field device is carried out by the master controller 42.

[0018] Therefore, the master controller 42 not only controls the communication controller 44 but also either actuators 46, 48 or a sensor 50 in the actuator/sensor 40. For each actuator 46, 48 there is provided a dedicated digital/analog converter unit 52, 54 while for the sensor 50 there is provided an analog/digital converter 56.

[0019] Further, it should be noted that while Fig. 2 shows a specific number of actuators and a single sensor according to the present a number of actuators and/or sensors in the actuator/sensor unit 40 is freely selectable and does not have impact on the different embodiments of the present invention to be described in the following.

[0020] Fig. 3 shows a more detailed schematic circuit diagram of the power converter unit 36 shown in Fig. 2.

[0021] As shown in Fig. 3, the power conversion unit 36 comprises a capacitor 58 connected across the input terminals of a DC/DC converter 60. Operatively, the capacitor 58 achieves a stabilization of the input voltage Ui to the DC/DC converter 60. The output voltage Uo of the DC/DC converter 60 is then forwarded to the subsequent controller unit 38.

[0022] Operatively, each field device 20, 22 connected to the intrinsically safe field bus segment 10 receives an operating current from the intrinsically safe field bus segment 10. When sending information from the field device to the intrinsically safe field bus segment 10 the current value for the operating current is determined through the modulating unit 34 under control of the communication controller 44. In other words, according to the control signal supplied from the communication controller 44 to the modulating unit 34 the operating current supplied to the field device and thus also the voltage of the intrinsically safe field bus segment 10 varies to achieve digital communication.

[0023] Here, it should be noted that the particular communication standard used for such a communication process is not to be construed as restricting the present invention to be described in the following.

[0024] Further, to receive information in the field device the communication controller 44 maintains the resistance value of the modulating unit 34 constant. Therefore, in case a different field device triggers a change of the voltage on the intrinsically safe field bus segment 10 the remaining field device(s) connected to this intrinsically safe field bus segment 10 may detect this change of the voltage via the connection lines 28, 30 for further processing thereof in the control unit 38. This digital communication mechanism is used to provide the master controller 42 in each field device with control information for activation of the actuators and/or sensors for manufacturing process control and surveillance.

[0025] As also shown in Fig. 2, each field device presents an effective capacitance Ceff to the intrinsically safe field bus segment 10.

[0026] It is for this reason that the discharge protection unit 32 is inserted between the intrinsically safe field bus segment 10 and the field device to avoid a discharge of the effective capacitance Ceff onto the intrinsically safe field bus segment 10 and therefore a disturbance of a communication process. Another reason is to avoid an overall capacitance on the intrinsically safe field bus segment 10 that might lead to the generation of sparks when somewhere a short circuit occurs on the intrinsically safe field bus segment 10.

[0027] On the other hand, in case the voltage of the intrinsically safe field bus segment 10 breaks down and therefore also the power supply to each field device. This power supply failure is not detected immediately by the controller unit 38 shown in Fig. 2 due to the energy stored in the field device, e.g., in the capacitor 58 shown in Fig. 3 or other capacitive/inductive circuit components in the field device stabilizing internal DC voltage.

[0028] It is for this reason that there occurs a delay between a decrease of the voltage on the intrinsically safe field bus segment 10 and the detection thereof at the controller unit 38 in case of a power supply failure.

[0029] However, once the controller unit 38 detects such a power supply failure it is not possible to store data in internal memories of the controller unit 38 that may be, e.g., related to internal states of the controller unit or sensed process variables or stored actuator command values since no more energy is available within the field device to carry out such a data saving procedure.

[0030] In other words, since the controller unit 38 detects a power supply failure only via the signal supplied from the power conversion unit 36 - i.e., an internal component of the field device - this detection is delayed with respect to the actual power supply failure on the intrinsically safe field bus segment 10 so that valuable time for the saving of internal data and actuator command values and sensed process variables in the controller unit 38 is lost.

SUMMARY OF INVENTION

[0031] In view of the above, a first object of the present invention is the detection of a power supply failure on the intrinsically safe field bus of a manufacturing process control system in an efficient manner.

[0032] A further object of the present invention is to provide a method for power supply failure detection in such a manufacturing process control system.

[0033] According to the present invention, the first object is achieved by a field device for monitoring a manufacturing process and for actuating manufacturing

process variables according to the claim 1.

[0034] According to the present invention it is proposed to detect a power supply failure on the intrinsically safe field bus not internally within a field device but through detection of a signal that is in direct relationship to the voltage on the intrinsically safe field bus segment without any delay caused by energy storage.

[0035] In other words, the inventor of the present invention has found that it is very advantageous to use one of the signals at internal nodes of the discharge protection unit of the field device that are not effected by the effective capacitance of the field device.

[0036] For this reason, as soon as a power supply failure occurs on the intrinsically safe field bus segment such a node signal will decline simultaneously with the voltage of the intrinsically safe field bus segment. It may therefore be used as an indication of power supply failure.

[0037] An important achievement of the present invention is to avoid the impact of internal energy storing elements - e.g., capacitors - on the power failure supply detection by deriving an interrupt signal for power supply failure indication in the first circuit stage of the field device for direct supply to the controller unit. Therefore, immediately on decline of, e.g., the voltage on the intrinsically safe field bus segment the controller unit becomes aware of such a power supply failure.

[0038] Since there expires a certain time interval between breakdown of the voltage on the intrinsically safe field bus segment and the power supply to the controller unit due to the energy stored internally in the field device this time interval may be used to save data stored in the controller unit, e.g., command data for the actuators, measurement data from the sensors or internal states thereof. Therefore, a controlled restart of the field device after recovery of the energy supply thereto is guaranteed. Also, the present invention allows to significantly improve the operative safety characteristic of the field device as any undefined controller states - e.g., false command values for the actuators - may be strictly avoided.

[0039] Yet another important advantage of the present invention is - as internal states, command and measurement data are saved - that the field device is fully operative immediately after recovery of the energy supplied thereto, thus avoiding time consuming resetting mechanisms in the manufacturing process control system or - even worse - an uncontrolled operation in the manufacturing field.

[0040] According to a preferred embodiment of the present invention the discharge protection unit comprises at least two rectifying elements inserted into the current path of the operating current with identical conducting directions being connected in series. Either an input signal or an output signal to a selected rectifying element may then be supplied as interrupt signal to the controller unit for a power supply failure detection.

[0041] The use of a cascade of rectifying elements with an identical conducting correction enables an easy variation of the redundancy level in the discharge protection unit, i.e. the degree to which a discharge of energy from the field device onto the control bus is avoided. The higher the number of the rectifier elements, the higher the redundancy level and degree of protection.

[0042] According to yet another preferred embodiment of the present invention the discharge protection unit comprises four rectifying elements connected in a full wave rectifier bridge network topology. Preferably, an additional rectifying element may be connected to a bridge arm node of the rectifier bridge network to increase the discharge protection redundancy level.

[0043] The use of a bridge network topology allows to adapt to different bus voltage polarities when connecting the field device to the intrinsically safe field bus segment. This preferred embodiment of the present invention is particularly useful when considering different communication standards that use different bus polarities.

[0044] Also, in case a further rectifier element is connected to the bridge arm node of the full wave rectifier bridge this allows to increase the intrinsic safety as the additional rectifier element blocks reverse current flow and related discharge of energy from the field device to the intrinsically safe field bus segment.

[0045] According to yet another preferred embodiment of the present invention an additional discharge protection element may be inserted into the line connecting an interrupt signal output terminal of the discharge protection unit and the controller unit.

[0046] Therefore, the concept to increase the intrinsic safety through insertion of rectifier elements into a current path may as well be applied to the supply of the interrupt signal to the controller unit. In other words, the provision of a discharge protection element in the line for the supply of the interrupt signal to the controller unit allows to achieve the same level of intrinsic safety for the supply of the operating current to the field device and the supply of the interrupt signal to the controller unit.

[0047] According to the present invention the second object outlined above is achieved through a method of operating a field device for monitoring a manufacturing process and for actuating manufacturing process variables having the features of claim 12.

[0048] Therefore, also the inventive method relies on the general gist of the present invention that is imperative to detect a power supply failure on the intrinsically safe field bus as soon as possible to guarantee that enough energy for the saving of internal states in the control unit of the field device is available.

[0049] Preferably, the triggering of the interrupt at the controller unit and the internal saving procedure in the controller unit is achieved using predetermined thresholds that are selected such that always a safe issuance of the interrupt signal and a safe storage of internal states after a power supply failure is guaranteed.

[0050] According to yet another preferred embodiment of the inventive method upon receipt of the power supply interrupt the controller unit turns off those power consumers in the field device which are not necessarily involved into the data saving procedure, e.g., liquid crystal displays or LED diodes.

[0051] This sophisticated power management achieves a longer time period for the saving of important data in the controller unit of the field device and thus a contribution to intrinsic safety of the field device.

[0052] According to yet another preferred embodiment of the inventive method the saving of internal states and data is carried out according to a predetermined priority scheme.

[0053] This embodiment of the inventive method is particularly useful in case data of different relevance and importance are stored in the memory of the controller unit.

[0054] Therefore, in view of scarce energy resources it is very advantageous to initially safe the most important data and to subsequently safe data of less relevance.

[0055] Here, it should be noted that different priorities may exist for different applications and that the inventive method is thus perfectly suited to improve operable safety for different applications through adaptation of predetermined priorities for the saving of internal data/ states for each single application.

[0056] According to yet another preferred embodiment of the present invention there is provided a computer program product directly loadable into the internal memory of a field device controller comprising software code portions for performing the inventive method when the product is run on the field device controller.

[0057] Therefore, the present invention is also provided to achieve an implementation of the inventive method steps on computer or processor systems. In conclusion, such implementation leads to the provision of computer program products for use with a computer system or more specifically a processor comprised in, e.g., a field device controller.

[0058] This programs defining the functions of the present invention can be delivered to a computer/processor in many forms, including, but not limited to information permanently stored on non-writable storage media, e.g., read only memory devices such as ROM or CD ROM discs readable by processors or computer I/O attachments; information stored on writable storage media, i.e. floppy discs and harddrives; or information convey to a computer/processor through communication media such as network and/or telephone networks and/ or internet via modems or other interface devices. It should be understood that such media, when carrying processor readable instructions implementing the inventive concept represent alternate embodiments of the present invention.

DESCRIPTION OF DRAWINGS

[0059] The best mode of carrying out the invention as well as further advantages, objects thereof and preferred embodiments will be described in the following with reference to the drawing in which:

Fig. 1	shows peripheral parts of a manufacturing process control system as technical background for the present invention;
Fig. 2	shows a schematic circuit diagram of the field device shown in Fig. 1;
Fig. 3	shows a schematic diagram of the power converter unit shown in Fig. 2;
Fig. 4	shows a schematic circuit diagram of a field device according to the present invention;
Fig. 5	shows a signal waveform diagram illustrating the impact of a power supply failure on the power supply signal to the controller in the field device shown in Fig. 4;
Fig.6	shows a flowchart of the method to operate a field device according to the present invention;
Fig. 7	shows a discharge protection unit providing an interrupt signal according to the present invention;
Fig. 8	shows another discharge protection unit providing an interrupt signal according to the present invention;
Fig. 9	shows another discharge protecting unit providing an interrupt signal according to the present invention;
Fig. 10	shows another discharge protecting unit providing an interrupt signal according to the present invention; and
Fig. 11	shows yet another discharge protection unit providing an interrupt signal according to the present invention.

BEST MODE OF CARRYING OUT THE INVENTION

[0060] Fig. 4 shows a schematic diagram for a field device according to the present invention. Those parts being identical to those previously discussed with respect to Fig. 4 or corresponding thereto are denoted using the same reference numerals and the explanation thereof will be omitted to avoid redundancy.

[0061] As shown in Fig. 4, the discharge protection

unit 32 according to the present invention is provided with an interrupt signal output terminal 62. As will be explained in more detail in the following, this interrupt signal output terminal 62 may be connected to any internal network node of the discharge protection unit 32, i.e. also to the input terminal or the output terminal of the discharge protection unit 32.

[0062] As also shown in Fig. 4, there is provided a interrupt signal line 64 connecting the interrupt signal output terminal 62 with the controller unit 68 of the field device. Preferably, a discharge protecting element 66 is inserted into the interrupt signal supply line 64 to avoid reverse current flow onto the intrinsically safe field bus segment 10 and therefore discharge of energy.

[0063] It is important to note that the discharge protection unit 32 only contains rectifying elements and therefore no energy storing components, e.g., capacitors. Therefore, as soon as the voltage on the intrinsically safe field bus segment 10 declines due to a power supply failure also the signal levels at internal nodes in the discharge protection unit 32 will decrease accordingly.

[0064] Operatively, as one of the internal node signals is connected to the interrupt signal output terminal 62 there is available an interrupt signal that decreases immediately when the bus voltage on the intrinsically safe field bus segment 10 decreases.

[0065] In other words, the signal at the interrupt signal output terminal 62 decreases instantly in case of a power supply failure while the output signal of the power conversion unit 36 supplying the controller unit 38 decreases only after a certain time period when the energy stored in the field device - e.g., in the capacitor 58 shown in Fig. 3 - is consumed.

[0066] It is an important aspect of the present invention that this time period may then be used to save internal states and/or command data and/or measurement data stored in the controller unit. One option is to store such data in a (not shown) non-volatile memory of the controller unit 38, e.g., an EEPROM memory (EEPROM = Electrically Erasible Programmable Read Only Memory). This will typically require some milliseconds of time.

[0067] Fig. 5 shows a signal waveform diagram illustrating the impact of a power supply failure on the intrinsically safe field bus segment onto the supply signal of the controller unit in more detail. In particular, the upper part of Fig. 5 shows the voltage on the intrinsically safe field bus segment 10 and the lower part of Fig. 5 shows the supply signal Uo for the controller unit 38 of the field device.

[0068] When a power supply failure occurs on the intrinsically safe field bus segment 10 the bus voltage will decrease from the nominal value to approximately a value of zero.

[0069] To avoid that every minor decrease of the bus voltage is interpreted as power supply failure, preferably a threshold comparison between the bus voltage UB and a minimum bus voltage $U_{B,min}$ - i.e. predetermined first threshold - is carried out to avoid an incorrect interrupt at the controller unit.

[0070] As shown in Fig. 5, in case the bus voltage UB becomes lower than the minimum required bus voltage $U_{B,min}$ at time t1 an interrupt signal is provided via the interrupt signal output terminal 62 of the discharge protection unit 32 to the controller unit 38 of the field device, e.g., in the form of a non-maskable interrupt.

[0071] As also shown in Fig. 5, the supply signal Uo at the output of the power conversion unit 36 only decreases after a certain period of time ΔT since energy is internally stored in the field device and may be used for further power supply of the controller unit also after occurrence of a power supply failure.

[0072] Therefore, during this period of time ΔT the controller unit 38 may be further operated to run a shutdown procedure and save internal states and/or command data and/or measurement data.

[0073] To guarantee that such a saving procedure is always run under definite operative conditions, the saving procedure should be terminated when the supply signal to the controller unit 38 gets lower than a minimum required supply signal $U_{o,min}$ at point of time t2.

[0074] Here, it should be noted that according to the present invention the specific values of the minimum bus voltage $U_{B,min}$ and the minimum required supply signal $U_{o,min}$ for the controller unit 38 are freely selectable parameters.

[0075] E.g., the higher $U_{B,min}$ and the lower the value of $U_{o,min}$, the longer the time period ΔT will be, however, at the risk of a slightly increased chance of a wrong interrupt signal or an operation of the controller unit 38 during the period ΔT with a supply signal Uo being too small. To the contrary, in case the value of $U_{B,min}$ is decreased and the value of $U_{o,min}$ is increased, the risk of a wrong interrupt is minimized and the controller unit 38 will always carry out a stable saving procedure, however, at the expense of a reduced time period ΔT. In conclusion, there exists a certain design trade off which is preferably decided in view of the considered application.

[0076] Further, while above the detection of a power supply failure has been discussed with respect to the voltage on the intrinsically safe field bus segment it should be clear that the same results may be achieved through detection of the operating current flowing into the field device, e.g., through detection of the current passing over the modulating unit 34. This current value may then be processed in an analog manner for a power failure detection. Alternatively, the signal may be supplied to a comparator (not shown) for a threshold comparison to derive a digital output indicating a power failure.

[0077] Further, in case the field device is provided with a dedicated energy buffer for supply of energy to the circuit components of the field device on occurrence of a power failure as described in the co-pending application "Load Voltage Controller For A Field Device And

Related Control Method" assigned to the same applicant and incorporated herein in full by reference, also the discharge signal to such a dedicated energy buffer may be used for power failure detection.

[0078] Fig. 6 shows a flowchart of the inventive method of operating a field device in more detail. While the flowchart refers to the bus voltage on the intrinsically safe field bus, it should be noted that it should equivalently applicable to the alternatives outlined above, i.e. the monitoring of an operating current flowing into the field device or the monitoring of a supply current flowing out of an energy buffer provided in the field device.

[0079] As shown in Fig. 6, the voltage on the intrinsically safe field bus segment is detected in step S1 and compared with a minimum required bus voltage $U_{B,min}$ in step S2. In case the bus voltage is higher than the minimum required value, the detection of the bus voltage is continued in step S1.

[0080] Concurrently to the step S1 and step S2 the signal available at the interrupt signal output terminal 62 of the discharge prevention unit 32 is supplied to the controller unit 38 of the field device. Therefore, the master controller 42 of the controller unit 38 may continuously scan the signal supplied via the interrupt signal output terminal 62 without any delay through energy storing circuit components of the field device, as outlined above.

[0081] As also shown in Fig. 6, subsequent to the detection of a power supply failure in step S2 it is checked whether the supply signal to the controller unit 32 of the field device is larger than the required minimum value $U_{o,min}$ in step S3. If this is not the case - e.g., in the rare case where a power supply failure occurs immediately after start of operation of the field device - the process shown in Fig. 6 branches off to step S4 to wait for the restart of the energy supply to the field device. Otherwise, the saving of internal states and/or command data and/or measurement data is started in step S5.

[0082] According to the embodiment shown in Fig. 6, it is assumed that the storage of internal states/data is segmented so that a further interrogation whether more internal states are to be saved may be carried out in step S6. In the affirmative case, it is then checked whether still enough energy is available for the controller unit 38 of the field device. If no more internal states/data are/is to be saved or no more energy is available, the procedure branches off to step S4 to wait for restart of energy. Otherwise, step S5 is repeated to write further internal states/data into the non-volatile memory of the controller unit 38.

[0083] The segmentation of the saving of internal states/data as shown in Fig. 6 allows for a repeated evaluation of the energy available for the controller unit 38 of the field device running the saving procedure. Therefore, no saving of internal states/data is carried out in case the energy supplied to the controller unit is not lying in an operative range to avoid incorrect storage of states/data and therefore a subsequent incorrect operation of the field device. This allows to contribute to the overall safe operation of the field device.

[0084] Still further, the sequential approach to the saving of internal states/data allows to introduce a priority scheme where more important states/data are safe before less relevant states/data with less impact on the overall safe operation of the field device.

[0085] Yet another embodiment of the present invention considers the structure of the software running in the controller. Here, the software comprises a plurality of so-called function blocks according to a variety of protocols. According to the present invention it is also possible to map the interrupt signal submitted to the controller unit for a power supply failure detection into a variable. This variable would be one of many transmitter variables available to function blocks executing in the field device. In case this variable indicates a power supply failure each function block could then take one last action before the shut down procedure and in the field device.

[0086] Fig. 7 (a) to (c) show a discharge protection unit providing an interrupt signal according to the present invention.

[0087] As shown in Fig. 7, the first discharge protection unit uses a cascade of diodes 68, 70, ..., 72 for discharge protection from the field device onto the intrinsically safe field bus segment 10.

[0088] Further, the interrupt signal may be branched off either from the input terminal, any intermediate node between the rectifying elements - e.g., diodes - of the discharge protection unit or the output terminal thereof, as shown in Fig. 7 (a) to (c).

[0089] Since the discharge protection unit shown in Fig. 7 comprises no energy storing circuit components, the voltage signal either at the input terminal, the output terminal or any internal node thereof will decrease concurrently to the bus voltage on the intrinsically safe field bus segment 10 on occurrence of a power supply failure.

[0090] As already outlined above, the interrupt signal output terminal 62 may be connected to a discharge protection element having a conducting direction running from the discharge protection unit 32 to the controller unit 38 to guarantee intrinsic safety in the field device also when detecting the bus voltage on the intrinsically safe bus signal 10.

[0091] Fig. 8 shows another discharge protecting unit providing an interrupt signal according to the present invention.

[0092] As shown in Fig. 8, the discharge protection unit is of the full bridge rectifier type, i.e. a Graetz--diode-bridge, and comprises four rectifying elements 74 to 80, e.g., diodes. As is known in the art, the different rectifying elements are arranged in a bridge-like form (shown in the lower part of Fig. 8) between a node a and d constituting the input terminals of the discharge protection unit 32 and further between nodes b, c constituting the output terminals of the discharge protection unit 32. Since such a circuit arrangement is commonly known in

the art, no further explanation thereof must be given.

[0093] Insofar as the present invention is concerned, the discharge protection unit 32 is provided with an additional interrupt signal output terminal 62 that is connected selectively to either node a, b, c, or d. Therefore, the node signal at any node a to d may be supplied to the controller unit 38 as interrupt signal to trigger the non-maskable interrupt at the controller unit.

[0094] Fig. 9 shows another discharge protection unit providing an interrupt signal according to the present invention. Those parts being identical to the circuit components described with respect to Fig. 8 are denoted using the same reference numerals and description thereof is omitted.

[0095] As shown in Fig. 9, the discharge protecting unit shown in Fig. 8 differs over the previously described discharge protecting unit shown in Fig. 8 in that an additional rectifying element 82 - e.g., a diode - is provided between node b and the output terminal node e of the discharge protecting unit 32 with its conducting direction to the output node e of the discharge protecting unit 32.

[0096] This additional rectifying element 82 allows to increase the intrinsic safety of the field device due to the additional rectifying element supporting a discharge protection from the field device onto the intrinsically safe field bus segment. According to the present invention, the interrupt signal output terminal 62 of the discharge protection unit 32 may be connected to any of the nodes a to e shown in Fig. 9 for a power failure detection.

[0097] Fig. 10 shows yet another discharge protection unit providing an interrupt signal according to the present invention. Again, those circuit elements that have been previously described with respect to Fig. 8 and 9 are denoted using the same reference numerals and description thereof is omitted.

[0098] The discharge protection unit shown in Fig. 10 differs over the previously described discharge protection unit shown in Fig. 9 in that the additional rectifying element 82 is moved over node b into the branch a-b and d-b of the full wave rectifier bridge. The discharge protection unit 32 shown in Fig. 10 achieves an increased level of discharge protection through provision of the additional rectifying elements 82-1, 82-2. The interrupt signal output terminal 62 may be connected to any node a, b, c, or d or any further internal node, e.g. between rectifying elements 74/82-1 and/or between rectifying elements 76/82-2.

[0099] Fig. 11 shows yet another discharge protection unit providing an interrupt signal according to the present invention. Those circuit elements being identical to the discharge protection unit discussed previously with respect to Fig. 10 are denoted using the same reference numerals and description thereof is omitted.

[0100] The discharge protection unit 32 shown in Fig. 11 differs over the discharge protecting unit shown in Fig. 10 in that a first resistor 84 and a second resistor 86 are connected in series between a line connecting the rectifier element 74 and the rectifier element 82-1 and a line connecting the rectifying element 76 and the rectifying element 82-2.

[0101] As shown in Fig. 11, a signal at the network node 88 between the first resistor 84 and the second resistor 86 is used as interrupt signal at the interrupt signal output terminal 62. Operatively, the additional resistors 84 and 86 allow for the determination of an appropriate interrupt signal level at the interrupt signal output terminal 62.

[0102] While in the above the present invention has been described with reference to circuit diagrams of preferred embodiments of the inventive field device, it should be noted that clearly the present invention may also be implemented using the method of operating a field device according to the present invention in a digital way using a microcontroller. In this case, the present invention may be embodied as a computer program product directly loadable into the internal memory of the controller unit comprising software code portions for implementing the inventive method.

[0103] Futher, it is understood that various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of the present invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims should be so construed as encompassing all the features of patentable novelty that reside in the present invention, including all features that would be treated as equivalent thereof by those skilled in the art to which the present invention pertains.

Claims

1. Field device for monitoring a manufacturing process and/or for actuating manufacturing process variables, comprising:

a) a discharge protection unit (32) being connected to a control bus (10) for supply of an operating current from the control bus (10) to the field device (20, 22) such that the discharge protection unit (32) inhibits a discharge of energy stored in the field device (20, 22) to the control bus (10);

b) a controller unit (38) adapted to control the operation of the field device (20, 22) and being powered with the operating current from the control bus (10); wherein

c) the discharge protection unit (32) comprises at least two rectifying elements inserted into the current path of the operating current with identical conducting directions and an input signal or an output signal of a selected rectifying element is supplied as interrupt signal to the con-

troller unit (38) for power supply failure detection.

2. Field device according to claim 1, ***characterized in that*** the discharge protection unit (32) is provided with an interrupt signal output terminal (62) being connected to an input or to an output of the selected rectifying element.

3. Field device according to claim 1 or 2, ***characterized in that*** it comprises an operating current modulating unit (34) being adapted to vary an effective resistance presented through the field device (20, 22) to the control bus (10) which operating current modulating unit (34) is serially connected to the discharge protection unit (32) for information exchange to/from the field device (20, 22) through operating current modulation under control of the controller unit (38).

4. Field device according to claim 3, ***characterized in that*** a power conversion unit (36) is connected in series between the operating current modulating unit (34) and the controller unit (38) for power supply of the controller unit (38) and/or actuators (46, 48) and/or sensors (50) of the field device (20, 22).

5. Field device according to one of the claims 1 to 4, ***characterized in that*** the discharge protection unit (32) comprises three rectifying elements (68, 70, 72) connected in series.

6. Field device according to one of the claims 1 to 4, ***characterized in that*** the discharge protection unit (32) comprises four rectifying elements (74-80) connected in a full wave rectifier bridge network topology.

7. Field device according to claim 6, ***characterized in that*** the discharge protection unit (32) further comprises an additional rectifying element (82) being connected to a bridge arm node (b) of the full wave rectifier bridge (74-80) at its input and to the operating current modulation unit (34) at its output.

8. Field device according to one of the claims 1 to 4, ***characterized in that*** the discharge protection unit (32) comprises six rectifying elements connected in a full wave rectifier bridge network topology, wherein the full wave rectifier bride has a first node (a) and a second node (d) connected to the control bus (10) and a third node (b) connected to a downstream circuit component (34) of the field device and a fourth node (c) connected to ground, further wherein a first rectifying element (78) having a first conduction direction is inserted between the first node (a) and the third node (c), a second rectifying element (80) having a second conduction direction is inserted between the fourth node (c) and the second node (d), a third rectifying element (74) and a fourth rectifying element (82-1) having the second conduction direction, respectively, are inserted between the first node (a) and the third node (b), and a fifth rectifying element (76) and a sixth rectifying element (82-2) having the first conduction direction, respectively, are inserted between the third node (b) and the second node (d).

9. Field device according to claim 8, ***characterized in that*** a first resistor (84) and a second resistor (86) are connected in series between a line connecting the third rectifying element (74) and the fourth rectifying element (82-1) and a line connecting the fifth rectifying element (76) and the sixth rectifying element (82-2) and that the signal at the network node (88) between the first resistor (84) and the second resistor (86) is used as interrupt signal at the interrupt signal output terminal (62).

10. Field device according to one of the claims 1 to 9, **characterized in that** a discharge protection element (66) is inserted in the line (64) connecting the interrupt signal output terminal (62) and the controller unit (38).

11. Field device according to one of the claims 1 to 10, **characterized in that** each rectifying element (72-82-2) and/or the discharge protection element (66) is a diode.

12. Method of operating a field device for monitoring a manufacturing process and/or for actuating manufacturing process variables, comprising the steps:

    a) continuously monitoring a voltage on a control bus (10) connecting the field device (20,22) with a central controller or an operating current flowing from the control bus (102) into the field device (20, 22);

    b) generating of a power supply interrupt signal when the monitored voltage/operating current decreases beyond a predetermined first threshold ($U_{B,min}$); and

    c) saving internal states in a field device controller (38) after supply of the power supply interrupt signal to the field device controller (38).

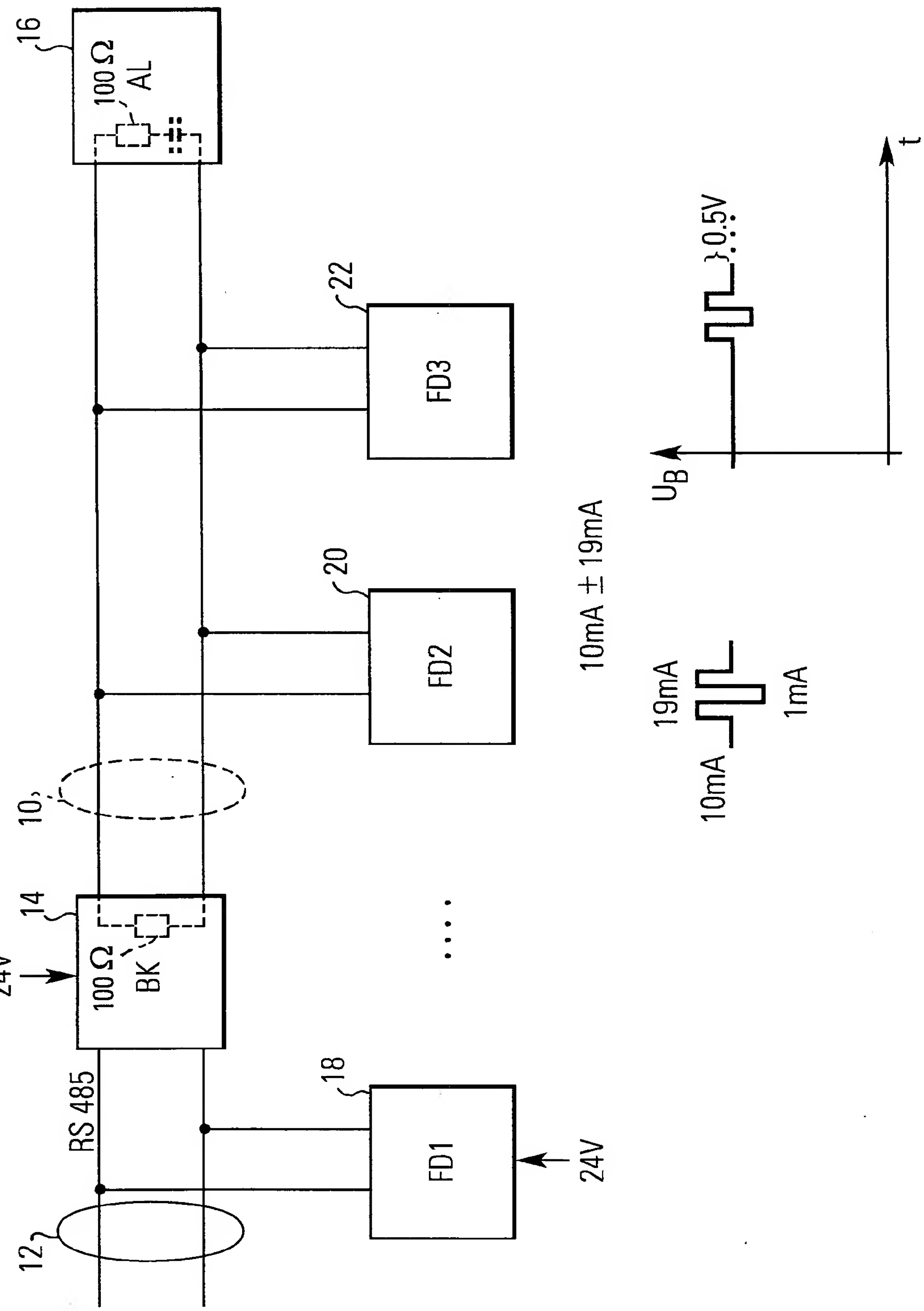
13. Method according to claim 12, ***characterized in that*** internal states of the field device controller are saved until the supply signal for the field device controller (38) decreases beyond a predetermined second threshold ($U_{o,min}$) or all internal states data are saved.

14. Method according to claim 12 or 13, ***characterized in that*** upon receipt of the power supply interrupt signal the field device controller (38) turns off power consumers in the field device for reduced power consumption.

15. Method according to one of the claims 12 to 14, **characterized in that** the saving of internal states is carried out according to a predetermined priority scheme.

16. Computer program product directly loadable into the internal memory of a field device controller (38) comprising software code portions for performing the steps of one of the method claims 12 to 15 when the product is run on the field device controller (38).

FIG.1


16
100 Ω
AL
22
FD3
20
FD2
10
14
24V
100 Ω
BK
18
RS 485
FD1
24V
12
10mA ± 19mA
19mA
10mA
1mA
U_B
0.5V
t

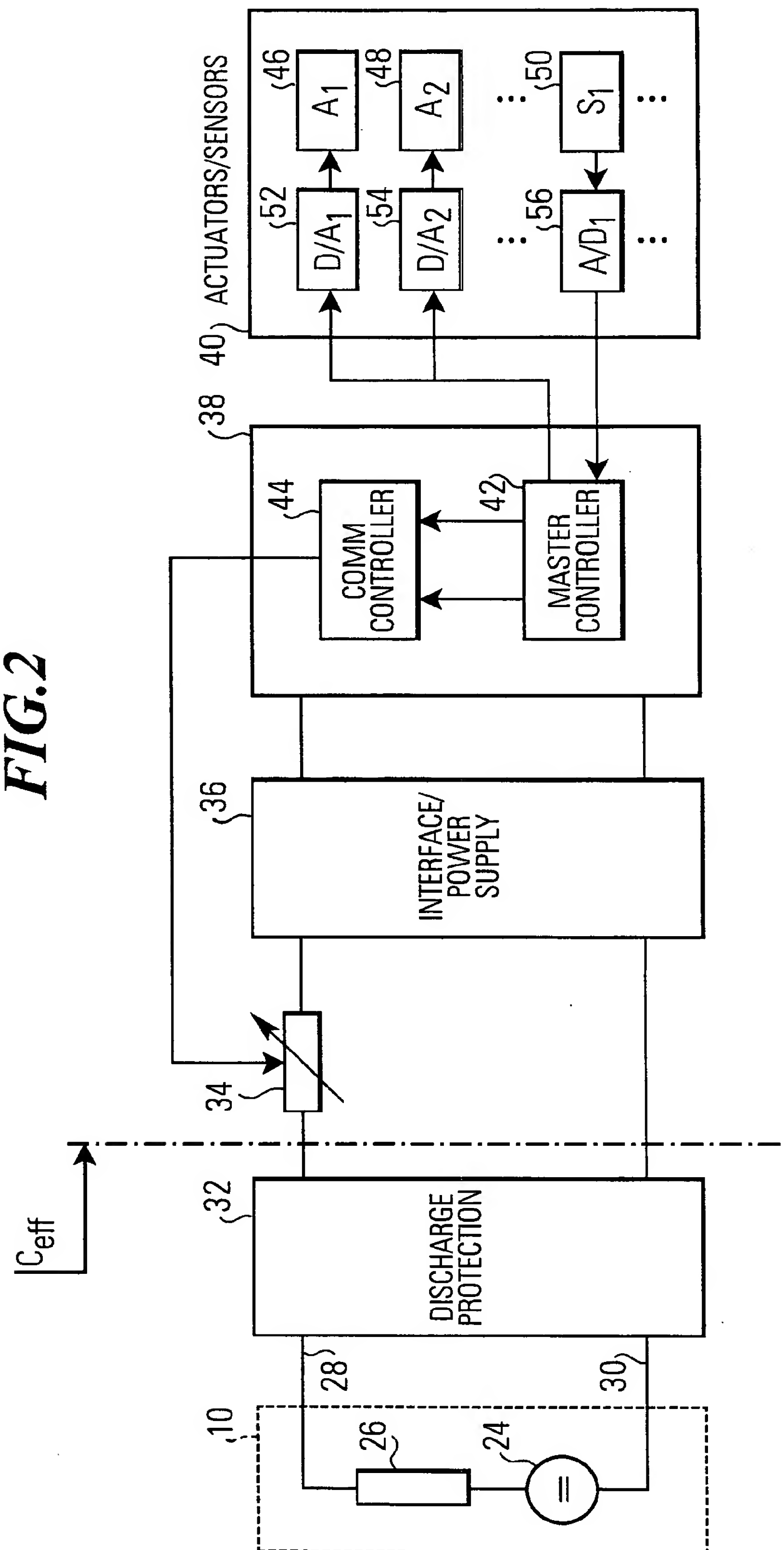
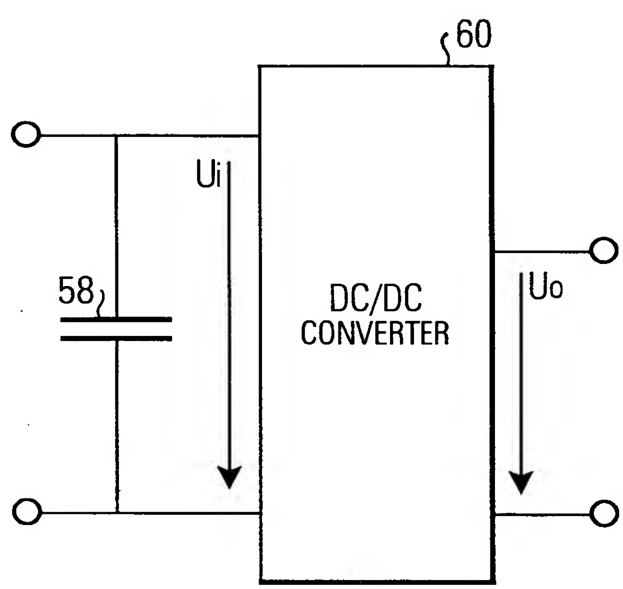
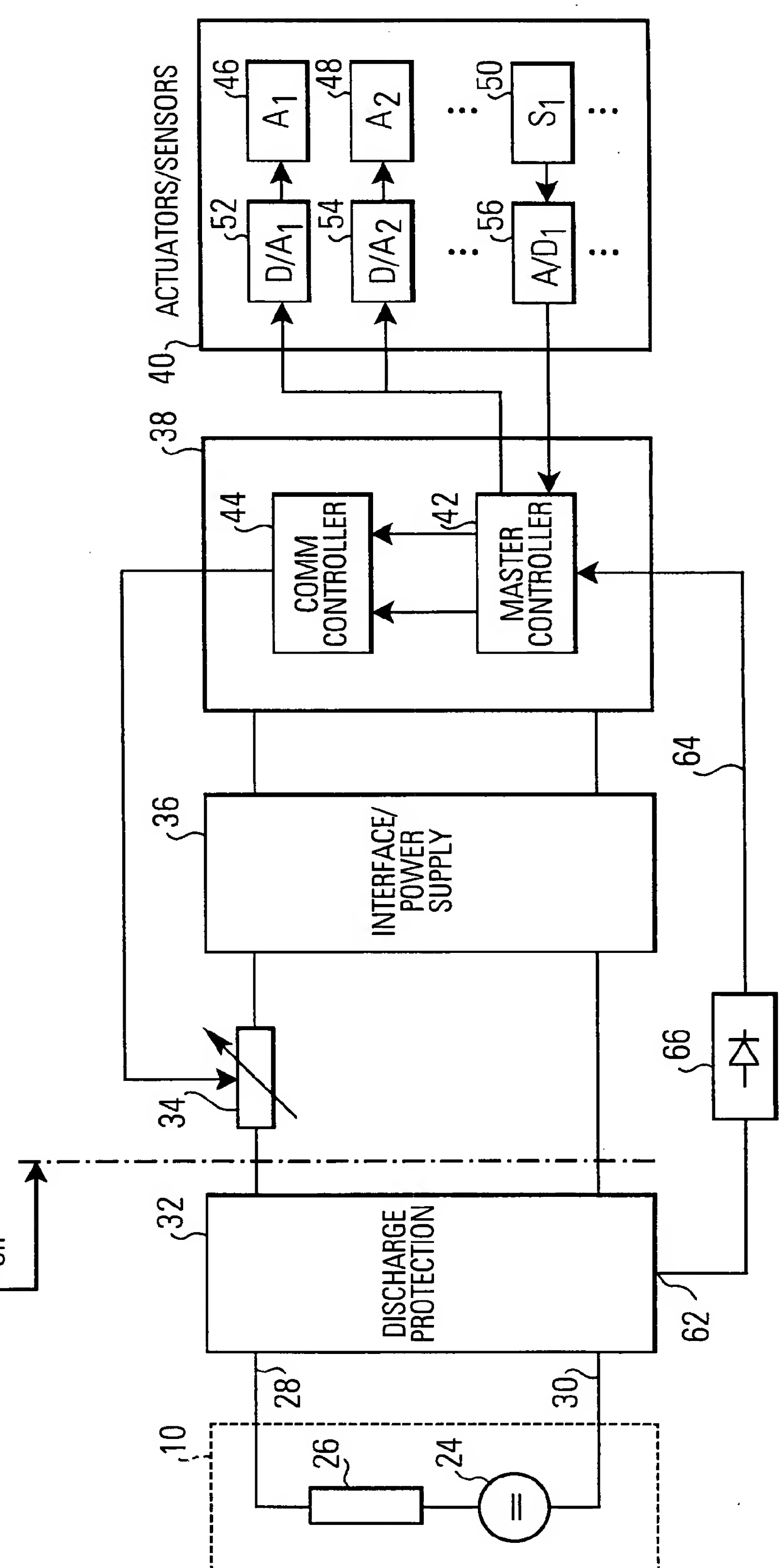

ACTUATORS/SENSORS
40
46
A1
48
A2
50
S1
52
D/A1
54
D/A2
56
A/D1
38
44
COMM CONTROLLER
42
MASTER CONTROLLER
36
INTERFACE/ POWER SUPPLY
34
Ceff
32
DISCHARGE PROTECTION
28
30
10
26
24

FIG.2

FIG.3

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A1
48
A2
50
S1
52
D/A1
54
D/A2
56
A/D1
38
44
COMM
CONTROLLER
42
MASTER
CONTROLLER
36
INTERFACE/
POWER
SUPPLY
64
34
66
Ceff
32
DISCHARGE
PROTECTION
62
10
26
24
28
30

FIG.4

FIG. 5

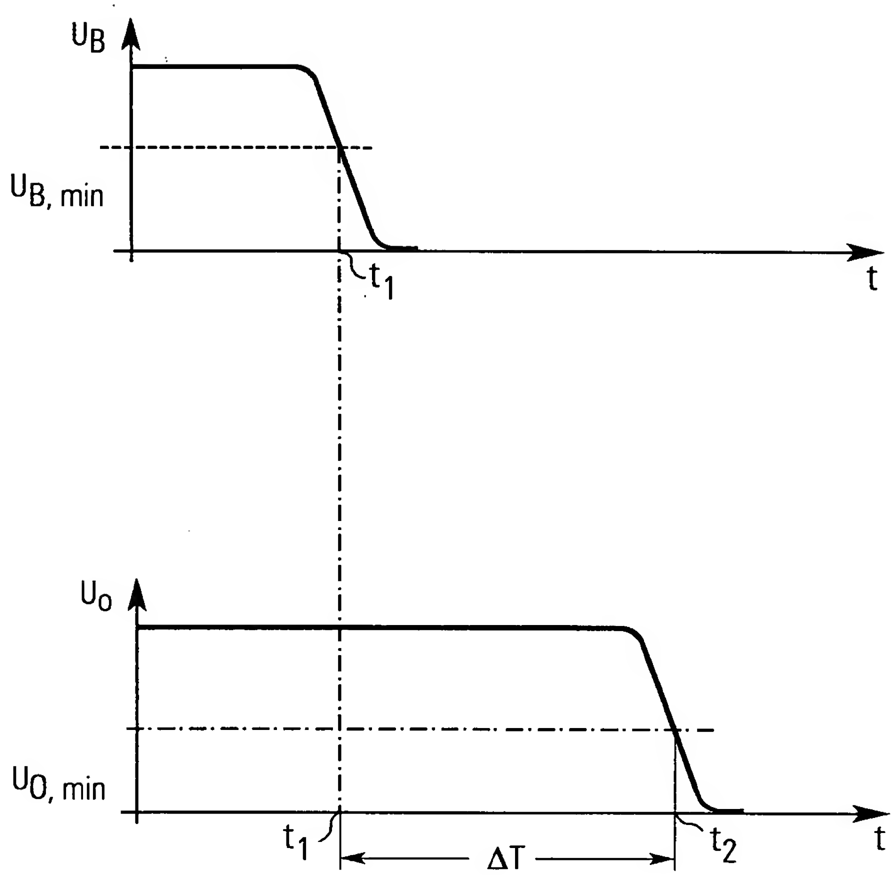


FIG.6

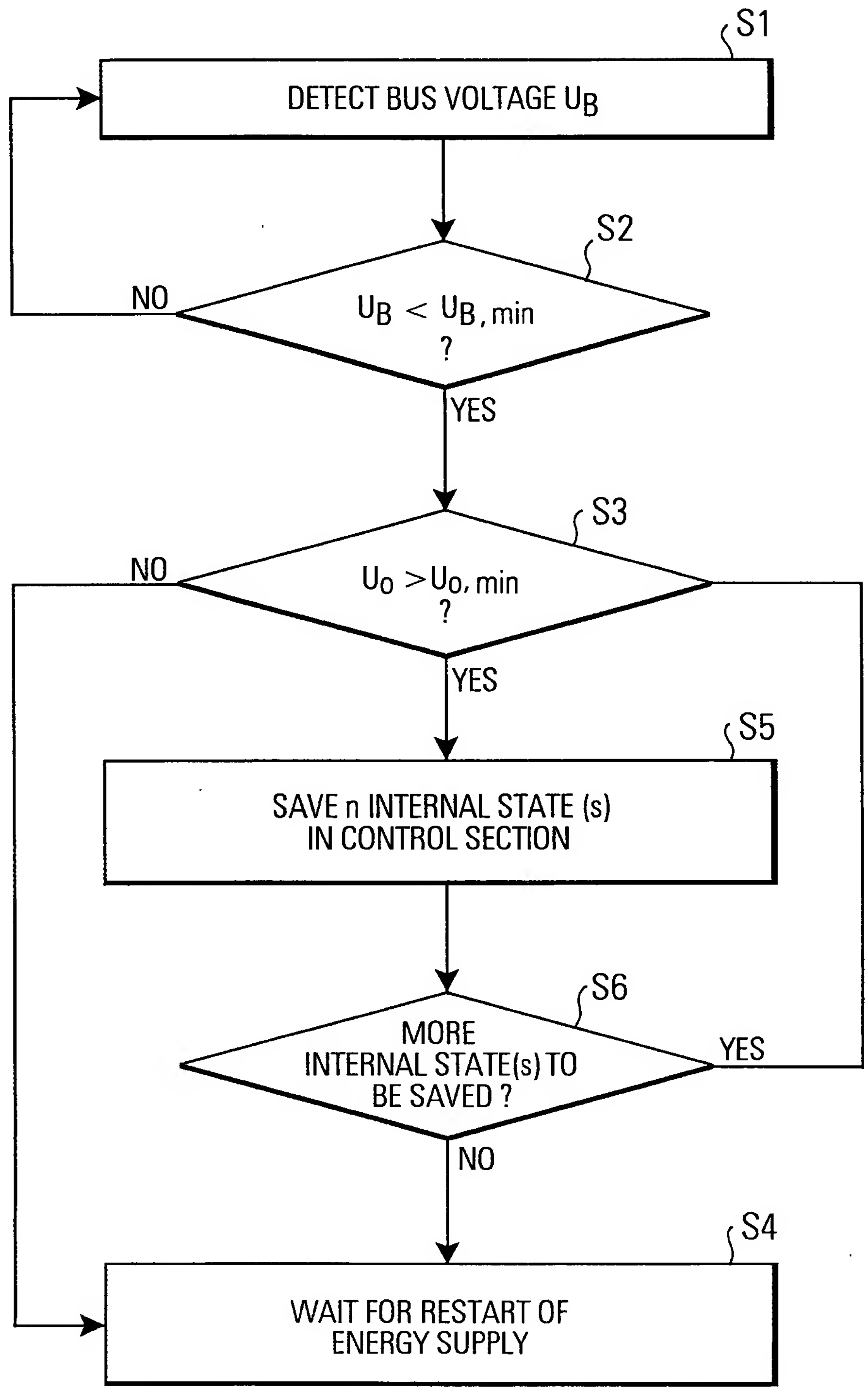

S1
DETECT BUS VOLTAGE U_B
S2
$U_B < U_{B,min}$?
NO
YES
S3
$U_o > U_{o,min}$?
NO
YES
S5
SAVE n INTERNAL STATE (s) IN CONTROL SECTION
S6
MORE INTERNAL STATE(s) TO BE SAVED ?
YES
NO
S4
WAIT FOR RESTART OF ENERGY SUPPLY

FIG. 7

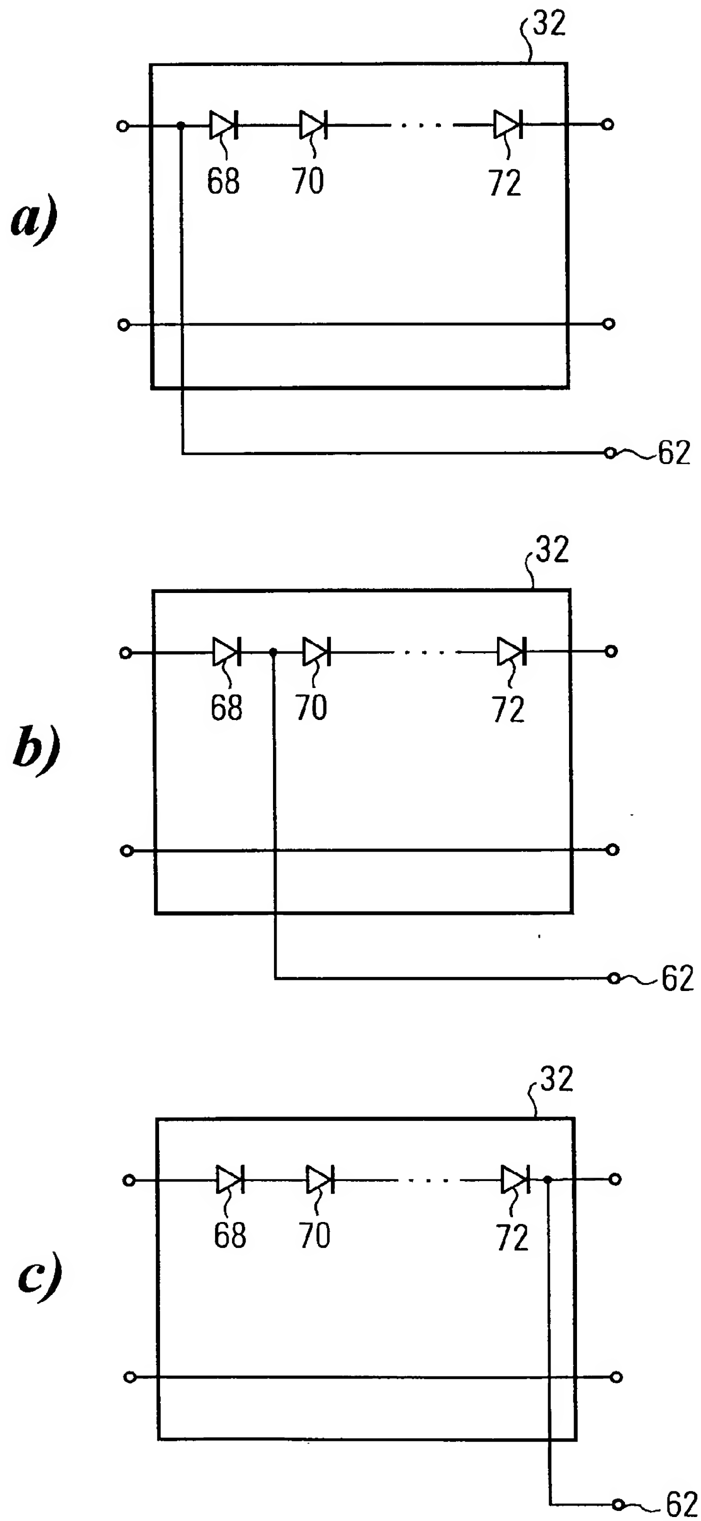
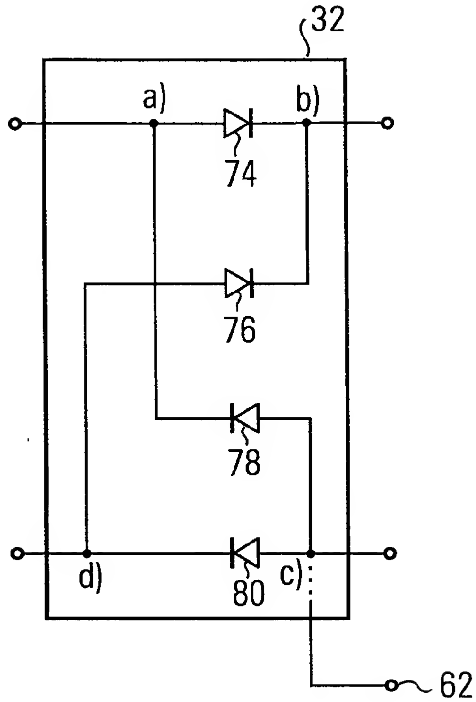


FIG.8



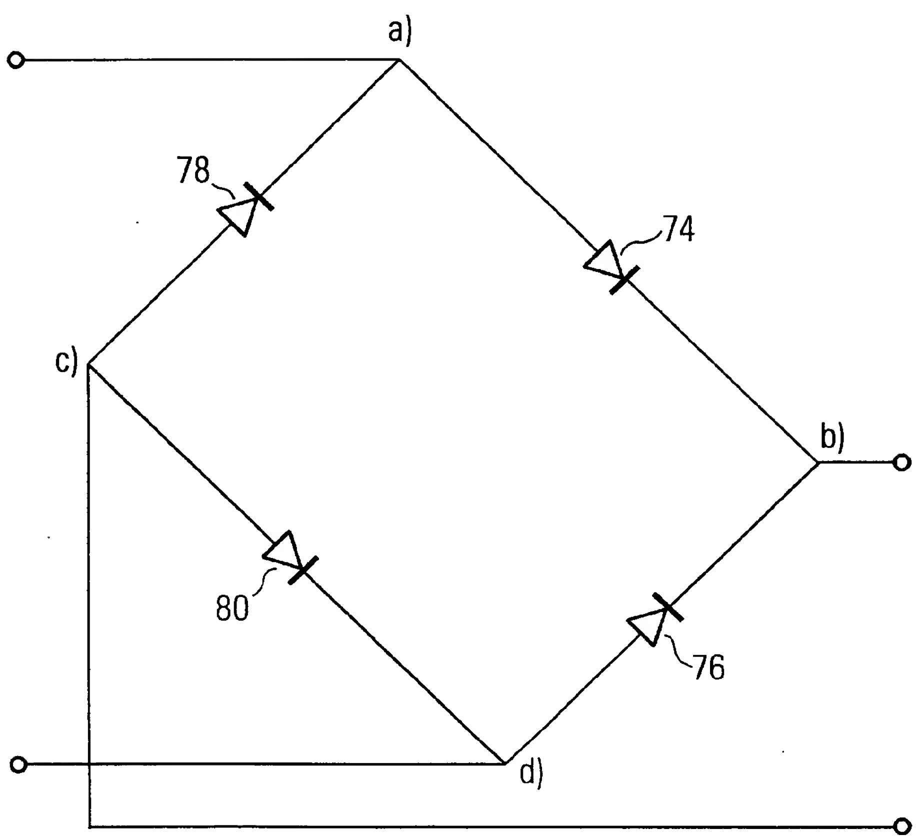


FIG.9

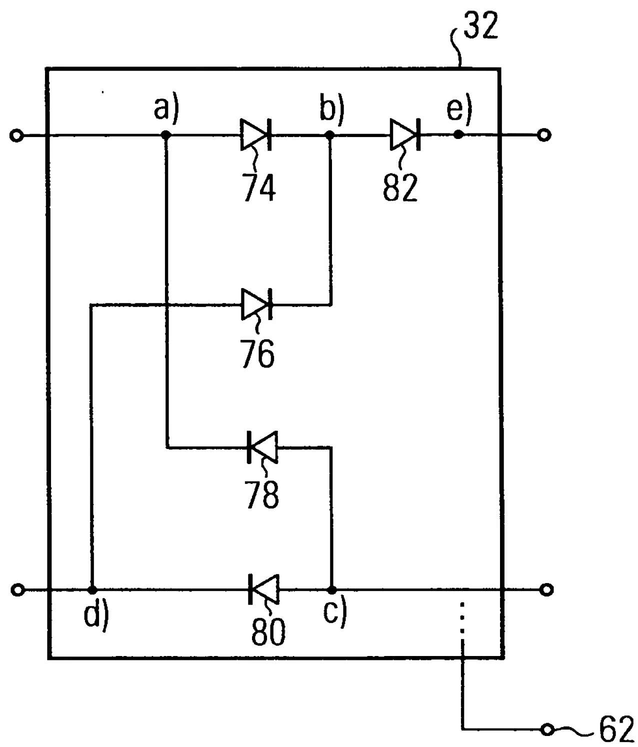


FIG.10

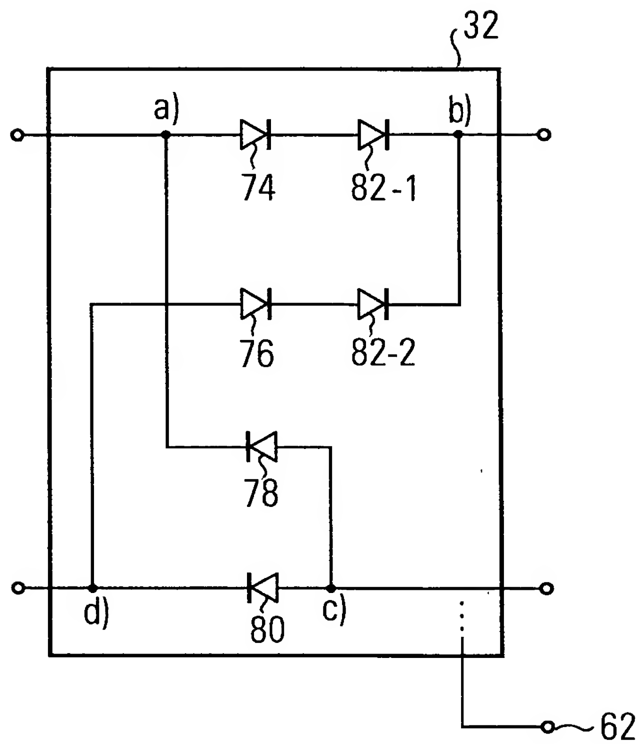
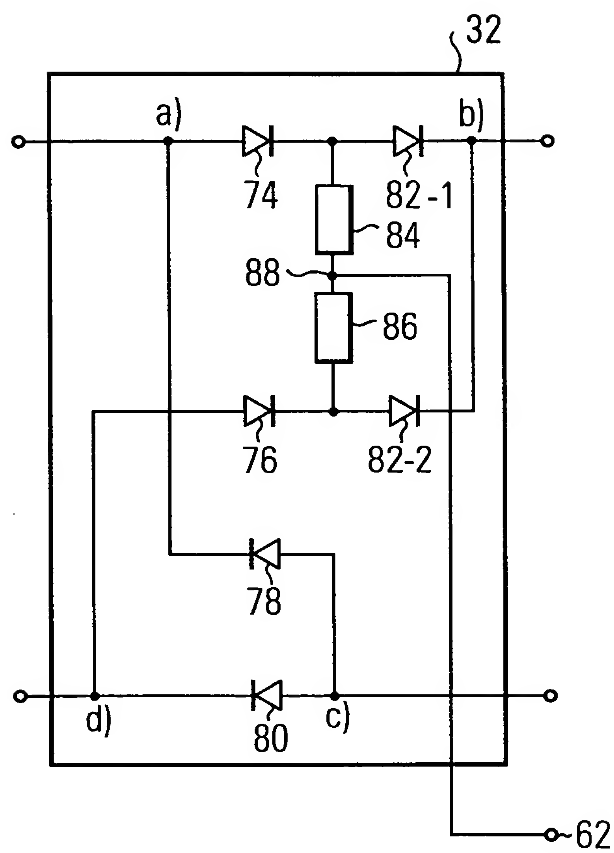


FIG.11



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 12 3342

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	US 4 584 651 A (CAREY JR JOHN L ET AL) 22 April 1986 (1986-04-22) * abstract *	1,12	G05B19/042
A	WO 99 45621 A (HARTMANN & BRAUN GMBH & CO KG ;VON ZUR GATHEN GUENTER (DE); WESTER) 10 September 1999 (1999-09-10) * abstract *	1,12	
A	DE 195 13 910 A (KH CONTROLS INC) 19 October 1995 (1995-10-19) * column 7, line 31 - column 8, line 3; figures 6,7 *	1,12	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

G05B
H02H

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	20 March 2001	Salm, R

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20-03-2001

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			US 5982594	A	09-11-1999
			ZA 9502981	A	21-12-1995

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